MATHEMATICAL MODELING OF A TRACTIONAL LINEAR ASYNCHRONOUS MOTOR

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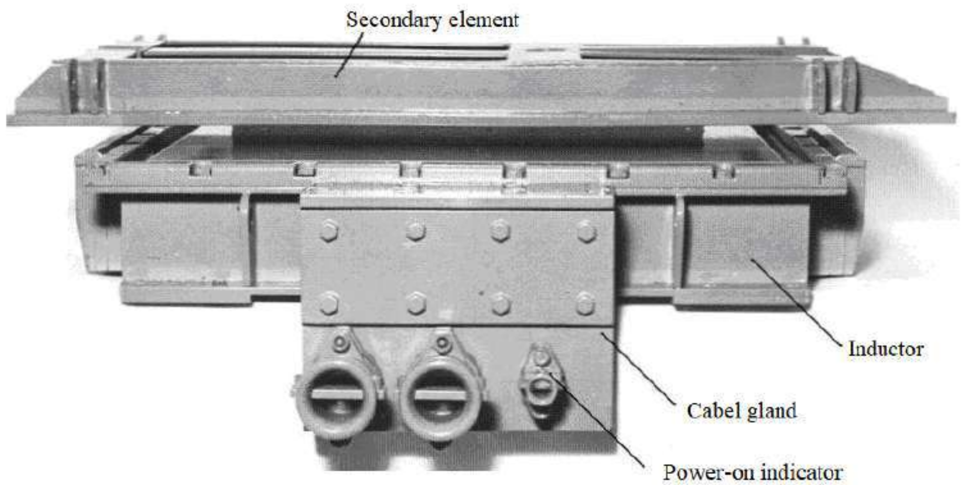
Abstract - The results of modeling a linear induction motor using the method of detailed equivalent circuit

Keywords - modeling, detailing, equivalent circuit, characteristics.

I. INTRODUCTION

In this paper the features of mathematical modeling of a traction linear induction motor (LIM) for freight or urban transport [1-7].

The basic parameters of the inductor of a three-phase linear asynchronous motor designed for driving a transport system: the length of the inductor is 2.24 (0.792) m, the width of its core is 0.5 (0.5) m, the thickness of the inductor is 0.13 (0.13) m,
the slot depth is 0.07 (0.064) m, the slot width is 0.06 / 2 (0.012) m, the tooth width is 0.033 / 2 (0.01) m, number of slots 24 (36). The secondary element (SE) is a bimetallic strip 0.7 (0.7) m in width. The thickness of the first aluminum (copper) layer is 8 (3) mm, the thickness of the second layer laminated from electrical steel sheets is 20 (steel massif 6) mm. The ratio of pole pitch to the equivalent non-magnetic gap is 15 (8.7), which corresponds to the recommendations for choosing the main dimensions of traction LIM [1,2,3,8]. The dimensions of the linear motor (Fig. 1) for driving a conveyor train manufactured by «Vzrivozashishennoe electrooborudovanie» SPA, Donetsk are shown in parentheses [8].



a

$$\mu t := \mu 0 \cdot (1\ \ 1\ \ 1\ \ 1\ \ 1.0\ \ 1\ \ 1\ \ 1\ \ 1.0\ \ 400\ \ 400\ \ 400\ \ 400.0\ \ 1)^T$$

$$\mu n := \mu t$$

$$h := 10^{-3} \cdot (3\ \ 2\ \ 2\ \ 2\ \ 2.0\ \ 2\ \ 2\ \ 2\ \ 2.0\ \ 4\ \ 6\ \ 5\ \ 5.0\ \ 5)^T$$

$$\gamma otn := 10^{-6} \cdot \left(1\ \ 1\ \ 1\ \ 1\ \ 1\ \ 1\cdot 10^{6}\ \ 1\cdot 10^{6}\ \ 1\cdot 10^{6}\ \ 1\cdot 10^{6}\ \ 1\ \ 1\ \ 1\ \ 1\ \ 1\right)^T$$

b

Fig. 1. General view (a) and layer structure of the 14-layer model (b) LIM

II. FORMULATION OF THE PROBLEM

Electromagnetic calculation of the linear asynchronous motor was carried using the detailed magnetic equivalent circuits (DMEC) [1.5.7] by MathCAD package, as well as using a two-dimensional version of the finite element field package of the Comsol Multiphysics. The influence of the third coordinate (the limited width of the secondary element) in the considered methods is taken into account using the Bolton's coefficient [1], and the electrical conductivity of the aluminum layer of the secondary element (SE) is multiplied to it. The parameters of the inductor in the DMEC method are calculated by the known expressions used for electrical machines of classical design [4]. The number of layers in the DMEC varies, that is reflected in its title - two-layer, six-layer, fourteen-layer. The number of sections along the longitudinal coordinate is taken equal to the number of slots in the inductor multiplied by 3 (24 sections in the active and two end zones). If the number of slots per pole and phase is q = 1, the total number of sections in the layer is 72, if the number of slots per pole and phase is q = 2, the total number of sections in the layer is 144. In the last case, the total number of contours and the number of equations of magnetic balance is equal to the product 144 by the number of selected layers. Since the layers, which contain the secondary element, are moving, an error arises in calculating the emf of motion (by magnetic fluxes along the tooth divisions) in the equations of electrical balance of the corresponding contours. The error can be reduced either by refining the formula for calculating the coordinate derivative [7], or by dividing the layers along the longitudinal coordinate by a larger number of sections, or both.

III. ANALYSIS OF THE RECEIVED RESULTS

This approach using the Bolton's coefficient applies for the so-called quasi-three-dimensional LIM models, for example [1,2,3,5]. It provides sufficient for engineering calculations accuracy of results using the modest computing resources. In addition, the application of the detailed magnetic equivalent circuits method provides easy way to integrate them into the full structural models of electromechanical systems contained a power supplies, a mechanical part, an automatic control system.

As noted above, the accuracy of calculating the characteristics of the motor by two-dimensional models depends to a large extent on the correctness of taking into account the influence of the dimensions of the inductor and the SE in the width (third coordinate).

In Fig. 2 the dependencies of the electrical conductivity (taking into account the Bolton's coefficient k_q) from the main dimensions of the motor and the material of the SE are shown.

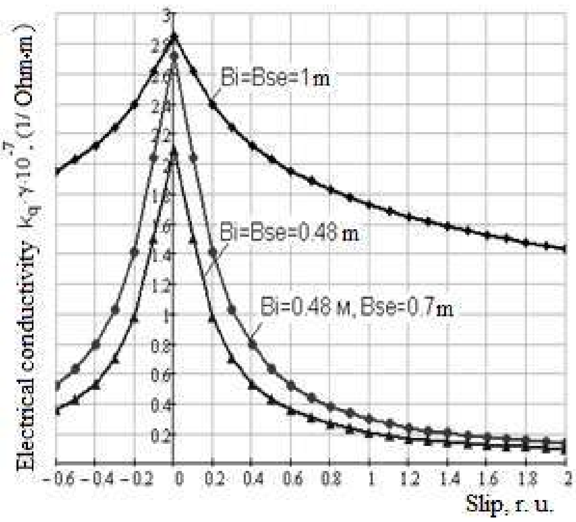


Fig. 2. Dependencies of the equivalent electrical conductivity taking into account the Bolton's coefficient from the slip, the width of the inductor is *Bi* and SE is *Bse*

As can be seen, this coefficient essentially depends on the transverse dimensions of the SE and inductor, and also on the slip. Certainly, this leads to the dependence of the traction forces F_T, the normal magnetic forces of the ferromagnetic cores F_{mg} and the oppositely directed levitation forces F_{lev} (Fig. 3a) from it. The lines show the characteristics calculated in the MathCad package. Also, there are the results of calculation of the levitation forces in the Comsol Multiphysics package for comparison.

It can be noted that the mechanical characteristic of the LIM for a given fixed phase current equal to 110 A (current density 1.6 A / mm^2) is close to the classical type with critical slip in the area of a small slip. The magnetic forces of the stator ferromagnetic cores and the SE are maximal in the area of small slip from -0.2 to +0.2, and the levitation forces acting on the SE are weakly dependent on the slip.

From the obtained result follows an important practical conclusion that by choosing the ratio of the width of the inductor and the width of the SE, it is possible to significantly influence the character of the change in the traction force as a function of the slip.

In Fig. 3b similar dependencies, when the width of the secondary element decreases to 0.48 m equal to the width of the inductor are shown. This reduces the electrical conductivity to transverse currents in a massive SE, that leads to an increase of the traction effort in the area of increased slip.

This conclusion can be used when choosing the width of the stationary secondary strip in the acceleration sections and the march segments of the track structure of the transport system.

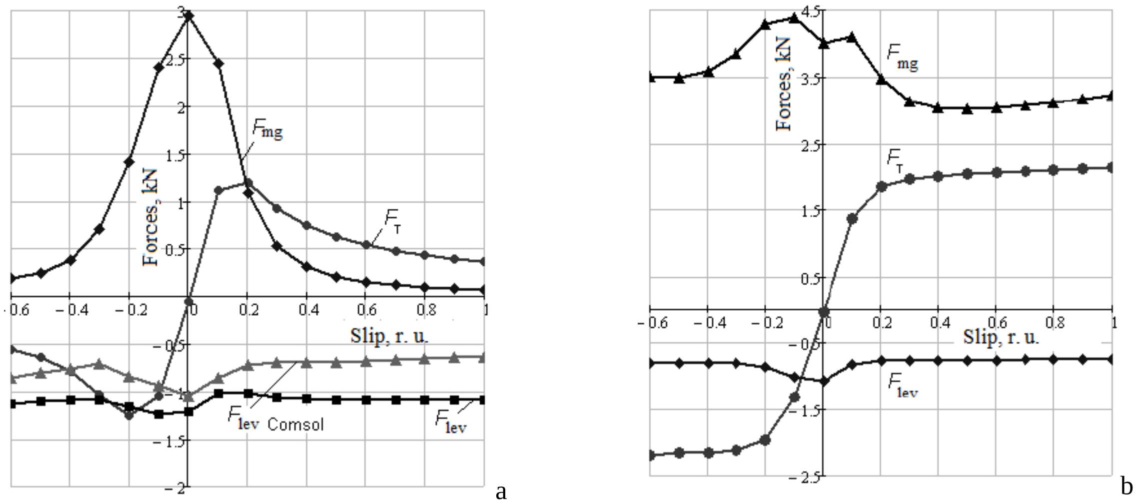


Fig. 3. Dependencies of traction and normal forces (magnetic and levitation) from slip: a) Bse = 0.7 m, Bi = 0.48 m; b) Bse = Bi=0.48 m

In Fig. 4 the traction characteristics of the LIM, obtained by the DMEC method with different number of the selected layers by thickness in the sectional view of the motor, and also by the Comsol Multiphysics are shown. It can be concluded that calculations using the detailed equivalent circuit method provide results that are close to the results of calculations based on the field package.

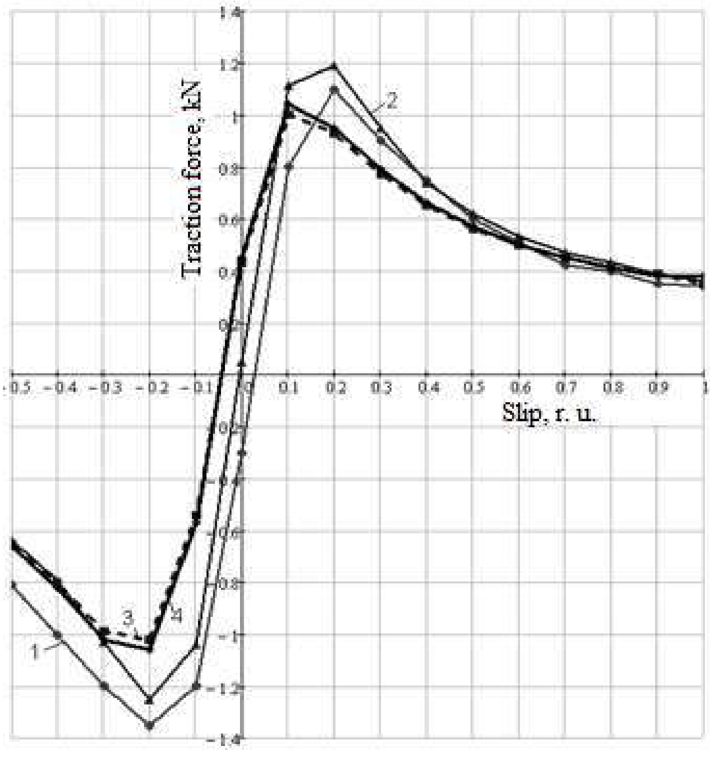


Fig. 4. Mechanical characteristics of LIM, Bse = 0.7 m, Bi = 0.476 m
1 – field package Comsol, 2 – 2-layer DMEC model, 3 – 6-layer DMEC model, 4 – 14-layer DMEC model

As noted above, in order to increase the accuracy with the two-layer DMEC, a refined form of the longitudinal coordinate derivative was introduced [6]. In Fig. 4 the mechanical characteristics of the LIM, obtained with a different allowances based on a two-layer DMEC with an inductor width and SE width, respectively Bi = Bse = 1 m are shown.

As can be seen, the greatest error is given by the variant with q = 1 without refinement in the calculation of the coordinate derivative. Transition to variants with a smaller step of the coordinate partitioning, refinement of the formula for calculating the coordinate derivative, or both allows to obtain results close to those obtained by a field package in the entire range of slip.

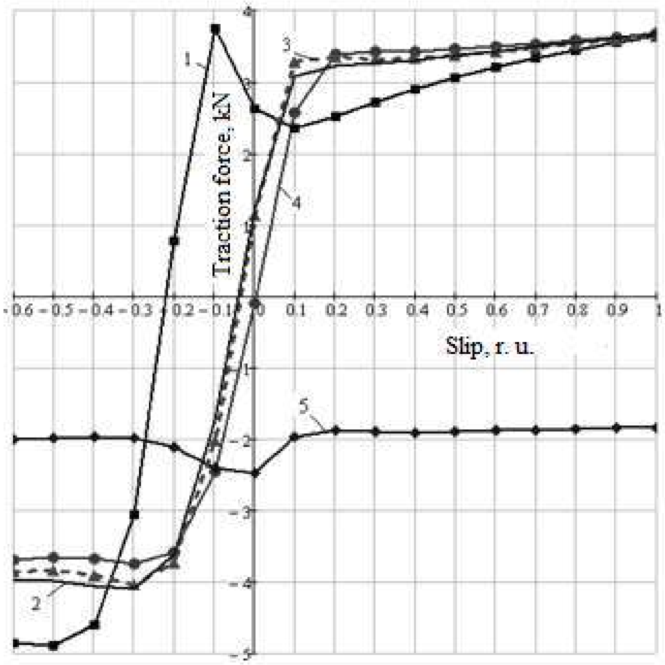


Рис.5. Dependencies of traction and normal forces from slip, obtained on the basis of 2-layer DMEC: 1) q = 1; 2) q = 2; 3) q = 1, correction [5] of the coordinate derivative; 4) q=2, correction of the coordinate derivative; 5) levitation force

IV. Conclusion

It can be concluded that the method of detailed magnetic equivalent circuits provides ample opportunities for analyzing the dynamic and static characteristics of linear asynchronous motors with sufficiently high accuracy of results.

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